Soil Biology & Biochemistry 83 (2015) 184–199

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Review paper

Microbial hotspots and hot moments in soil: Concept & review

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ARTICLE INFO

Article history:
Received 5 September 2014
Received in revised form
21 January 2015
Accepted 22 January 2015
Available online 10 February 2015

Keywords:
C and N cycles
Microbial activities
Priming effects
Microbial successions
Subsoil processes
Active microorganisms
Microbiota-habitat interactions

ABSTRACT

Soils are the most heterogeneous parts of the biosphere, with an extremely high differentiation of properties and processes within nano- to macroscales. The spatial and temporal heterogeneity of input of labile organics by plants creates microbial hotspots over short periods of time – the hot moments. We define microbial hotspots as small soil volumes with much faster process rates and much more intensive interactions compared to the average soil conditions. Such hotspots are found in the rhizosphere, detritusphere, biopores (including drilosphere) and on aggregate surfaces, but hotspots are frequently of mixed origin. Hot moments are short-term events or sequences of events inducing accelerated process rates as compared to the average rates. Thus, *hotspots and hot moments are defined by dynamic characteristics, i.e. by process rates*.

For this hotspot concept we extensively reviewed and examined the localization and size of hotspots, spatial distribution and visualization approaches, transport of labile C to and from hotspots, lifetime and process intensities, with a special focus on process rates and microbial activities. The fraction of active microorganisms in hotspots is 2–20 times higher than in the bulk soil, and their specific activities (i.e. respiration, microbial growth, mineralization potential, enzyme activities, RNA/DNA ratio) may also be much higher. The duration of hot moments in the rhizosphere is limited and is controlled by the length of the input of labile organics. It can last a few hours up to a few days. In the detritusphere, however, the duration of hot moments is regulated by the output – by decomposition rates of litter – and lasts for weeks and months. Hot moments induce succession in microbial communities and intense intra- and interspecific competition affecting C use efficiency, microbial growth and turnover. The faster turnover and lower C use efficiency in hotspots counterbalances the high C inputs, leading to the absence of strong increases in C stocks. Consequently, the *intensification of fluxes is much stronger than the increase of pools*. Maintenance of stoichiometric ratios by accelerated microbial growth in hotspots requires additional nutrients (e.g. N and P), causing their microbial mining from soil organic matter, i.e. priming effects. Consequently, *priming effects are localized in microbial hotspots and are consequences of hot moments*. We estimated the contribution of the hotspots to the whole soil profile and suggested that, irrespective of their volume, the hotspots are mainly responsible for the ecologically relevant processes in soil. By this review, we raised the importance of concepts and ecological theory of distribution and functioning of microorganisms in soil.

1. Introduction: definitions and the most important hotspots

1.1. Definitions and concept

The most ecologically relevant biogeochemical processes in soils are microbially mediated. Despite the enormous amount of microbial cells, i.e. 10^7–10^{12} in one gram soil (Watt et al., 2006), their localization is restricted to very small microhabitats comprising much less than 1% of total soil volume (Young et al., 2008) and globally covering merely 10^{-6} % of the soil surface area (Young and Crawford, 2004). Many soil microorganisms tend to form colonies and biofilms and tend to aggregate (Hodge et al., 1998; Ekschmitt et al., 2005), forming microbial hotspots. Consequently, ecologically relevant biogeochemical processes mainly occur in the small volume of soil **hotspots**. We define microbial **hotspots** as small soil volumes with much faster process rates and

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http://dx.doi.org/10.1016/j.soilbio.2015.01.025